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Portable data acquisition and storage system for monitoring patient

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Abstract

The system enables ambulatory monitoring of a patient's blood pressure and heart rate without the need for the patient to wear a portable magnetic tape recorder. ECG electrodes and a blood pressure cuff are affixed to the patient and are connected to a blood pressure measuring apparatus worn by the patient. The Data Acquisition and Storage System (DAS) is connected to the blood pressure measuring apparatus and includes a solid state storage device in which the successive measurements are stored. After the monitoring session, which may last 24 hours, the patient returns to the clinic, where the DAS is connected to a stationary chart that prints and plots the stored data in tabular and graphical form. The DAS includes a clock for determining the time at which the readings are taken, and these times are stored along with the data. The clock also permits the heart rate to be determined and stored by the DAS. If the voltage of the power source should fall too low the DAS goes into a dormant mode to preserve already stored data.

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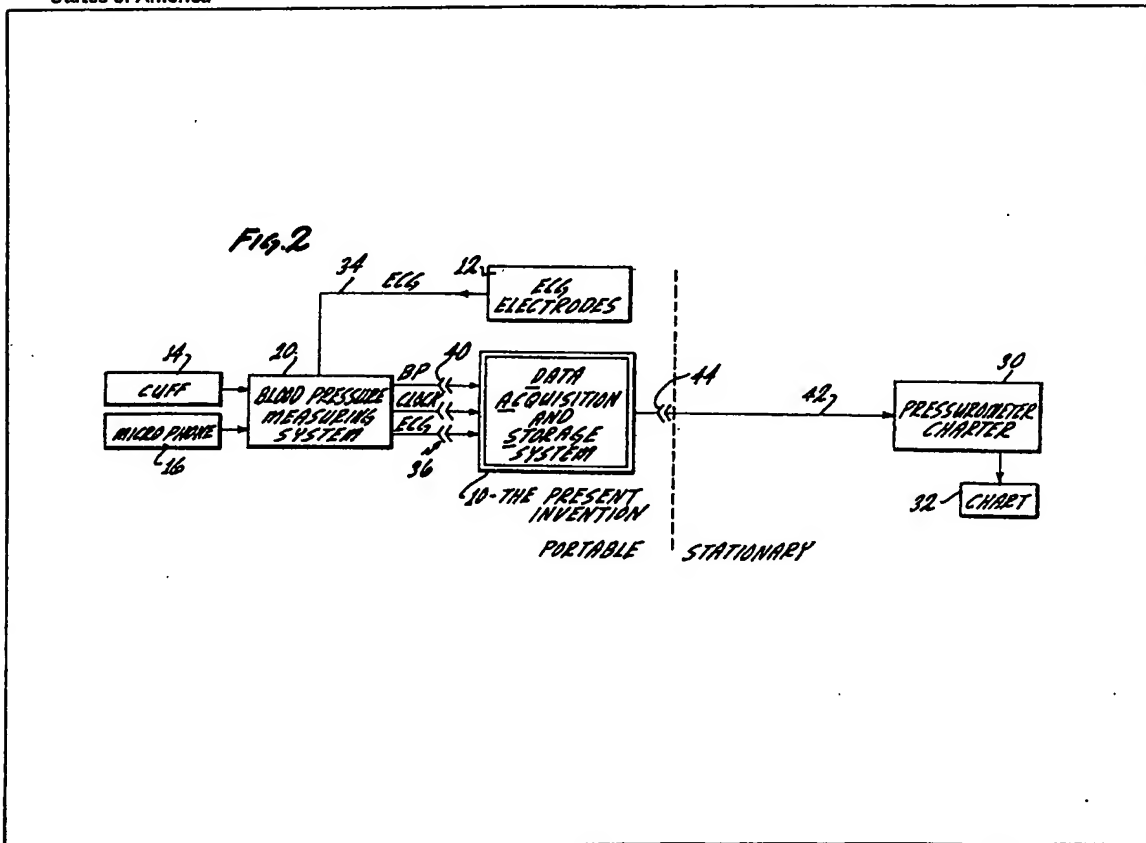
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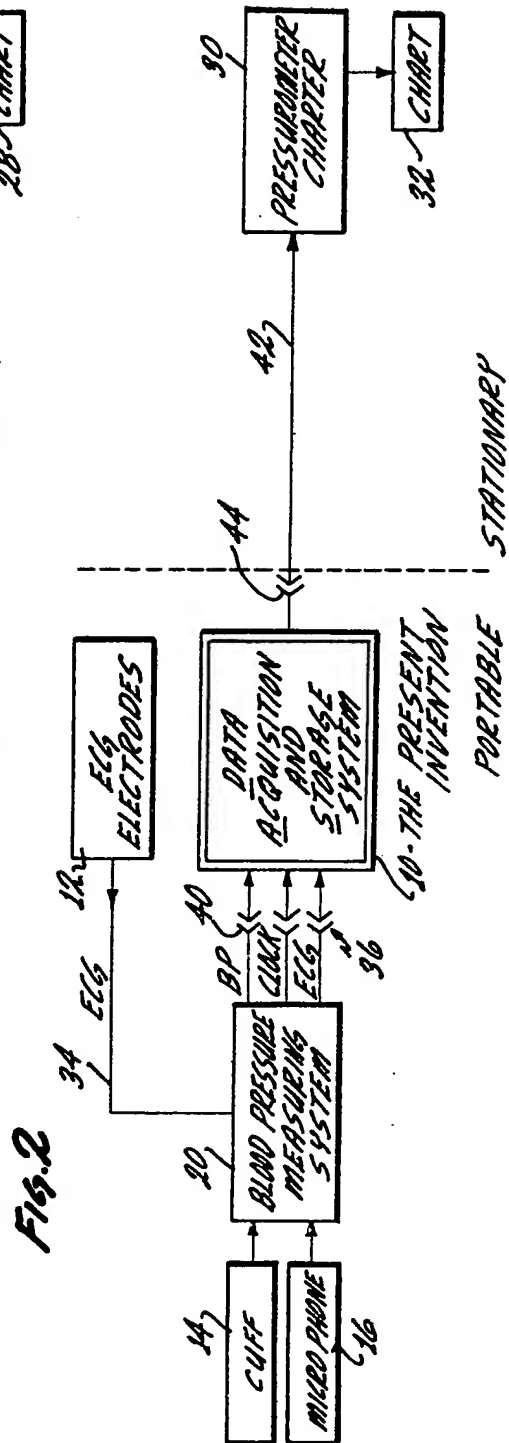
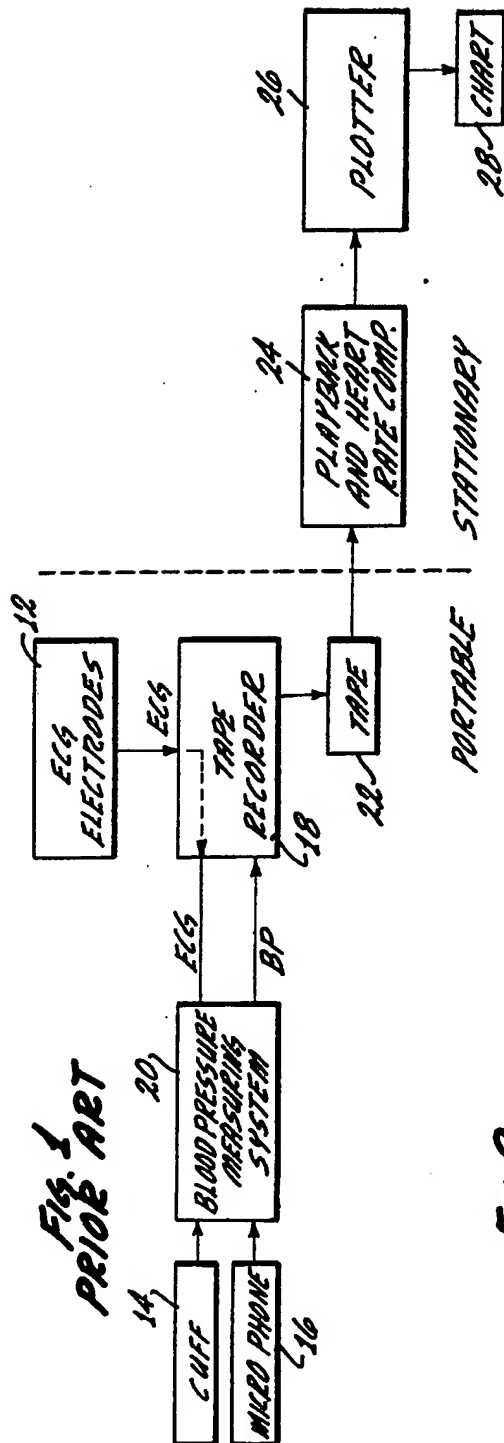
(54) Portable data acquisition and storage system for monitoring patient

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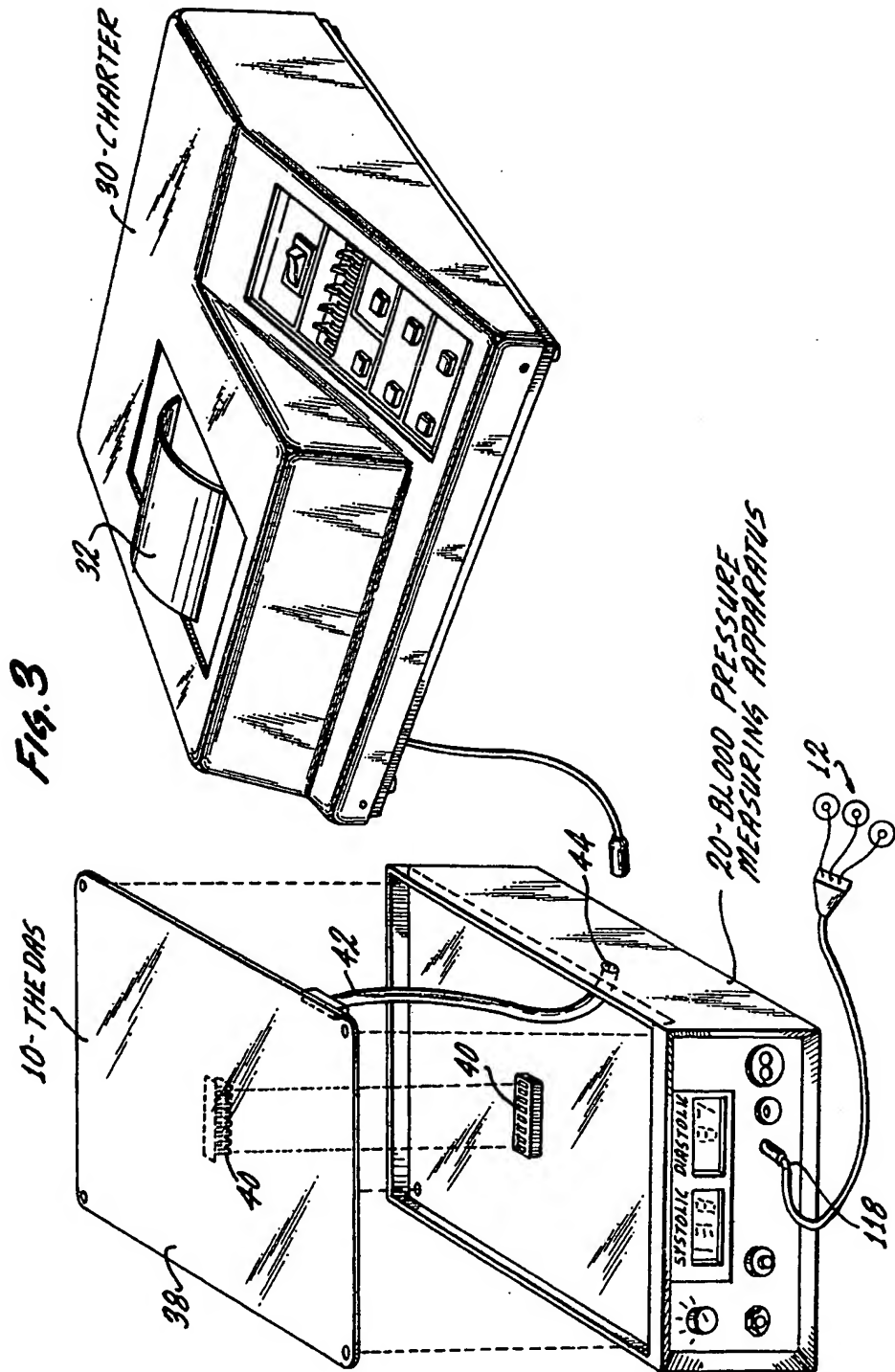


Fig. 4 - DATA ACQUISITION AND STORAGE SYSTEM BLOCK DIAGRAM

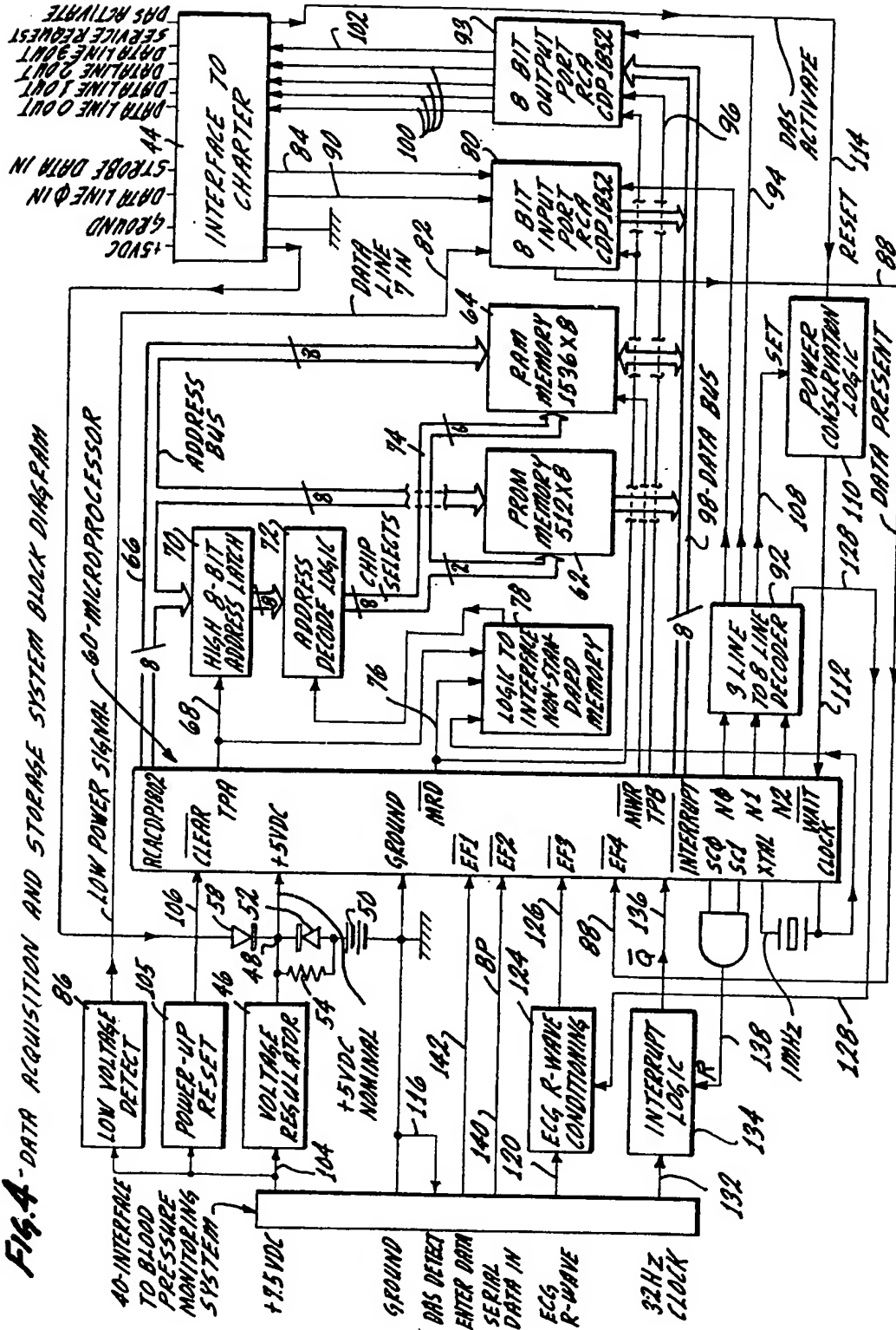


FIG. 5 INPUT SIGNAL TIMING DIAGRAM

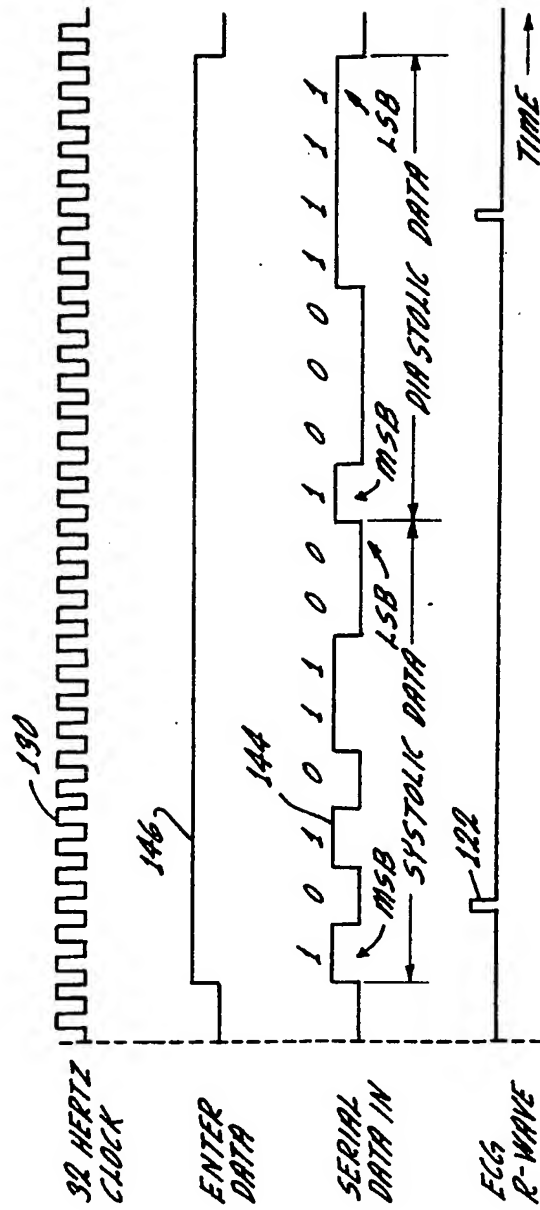


FIG. 6
OUTPUT
SIGNAL
FORMAT

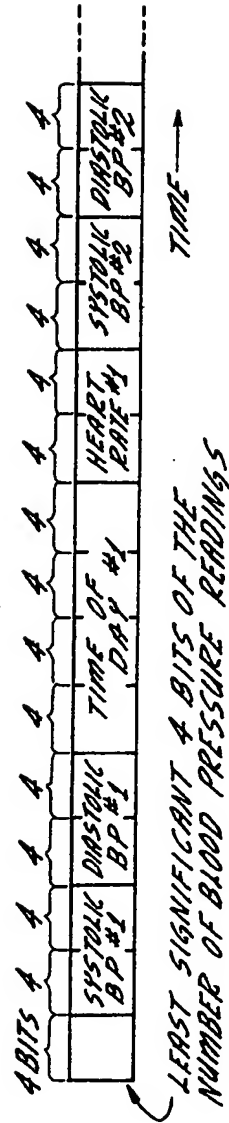
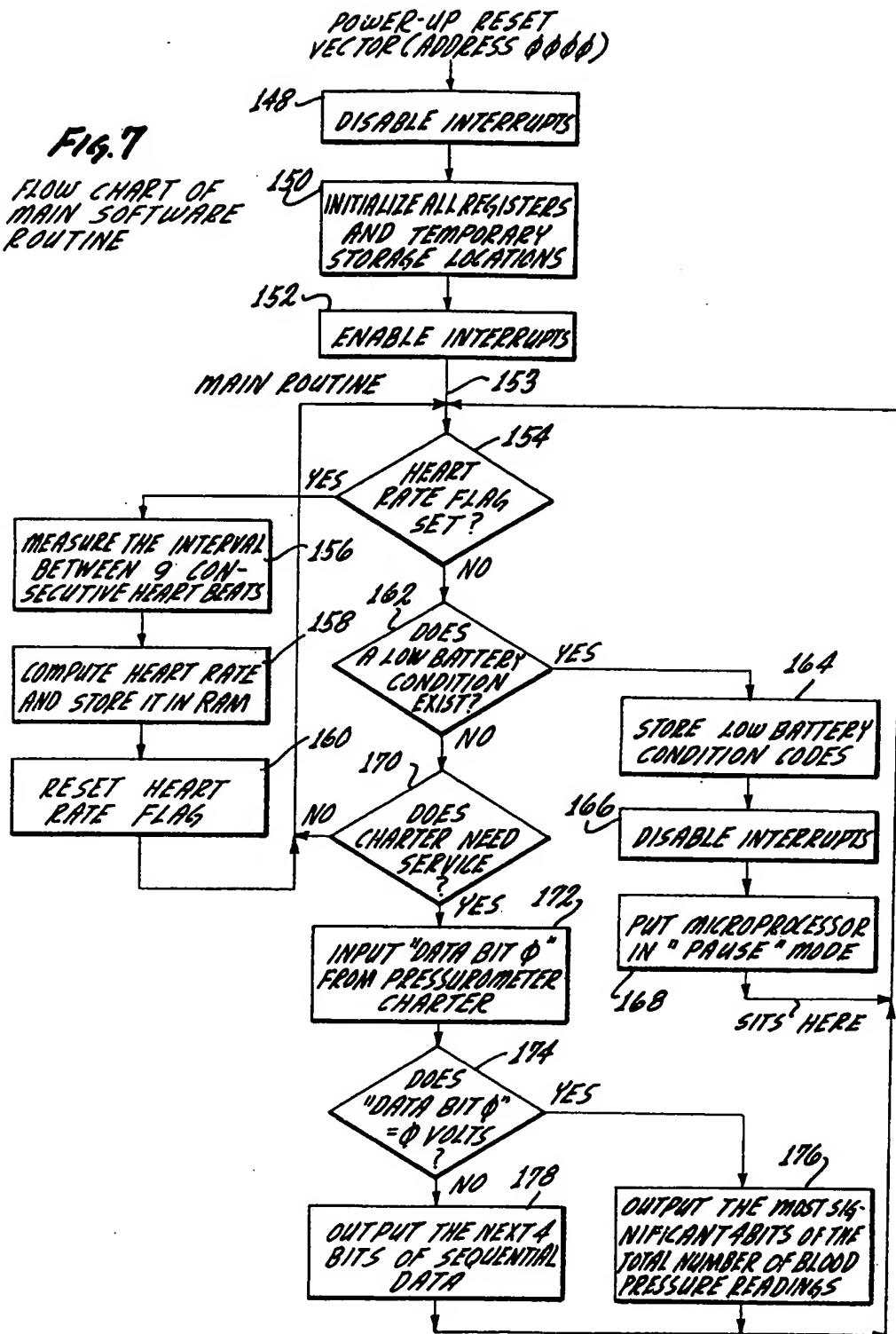
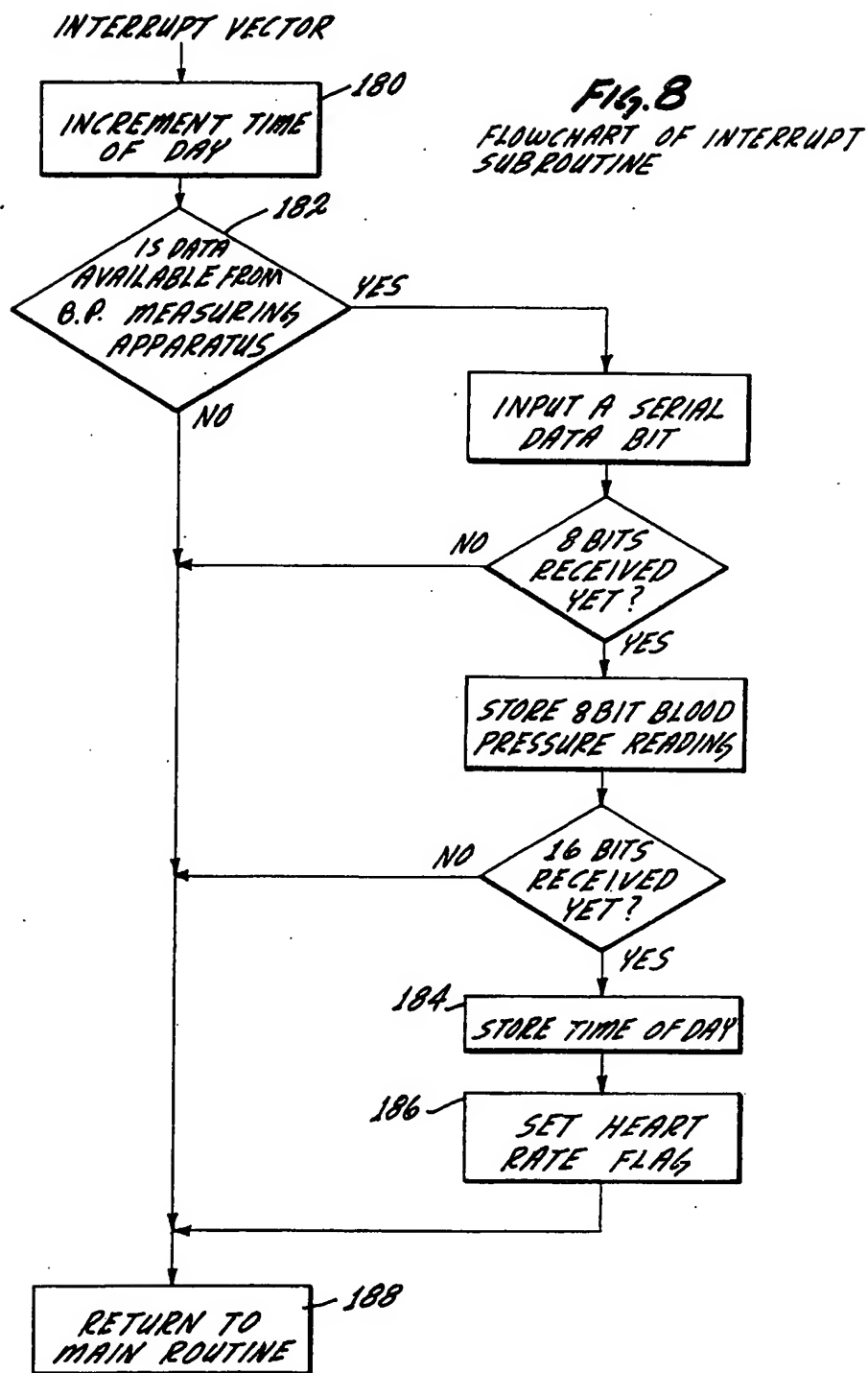
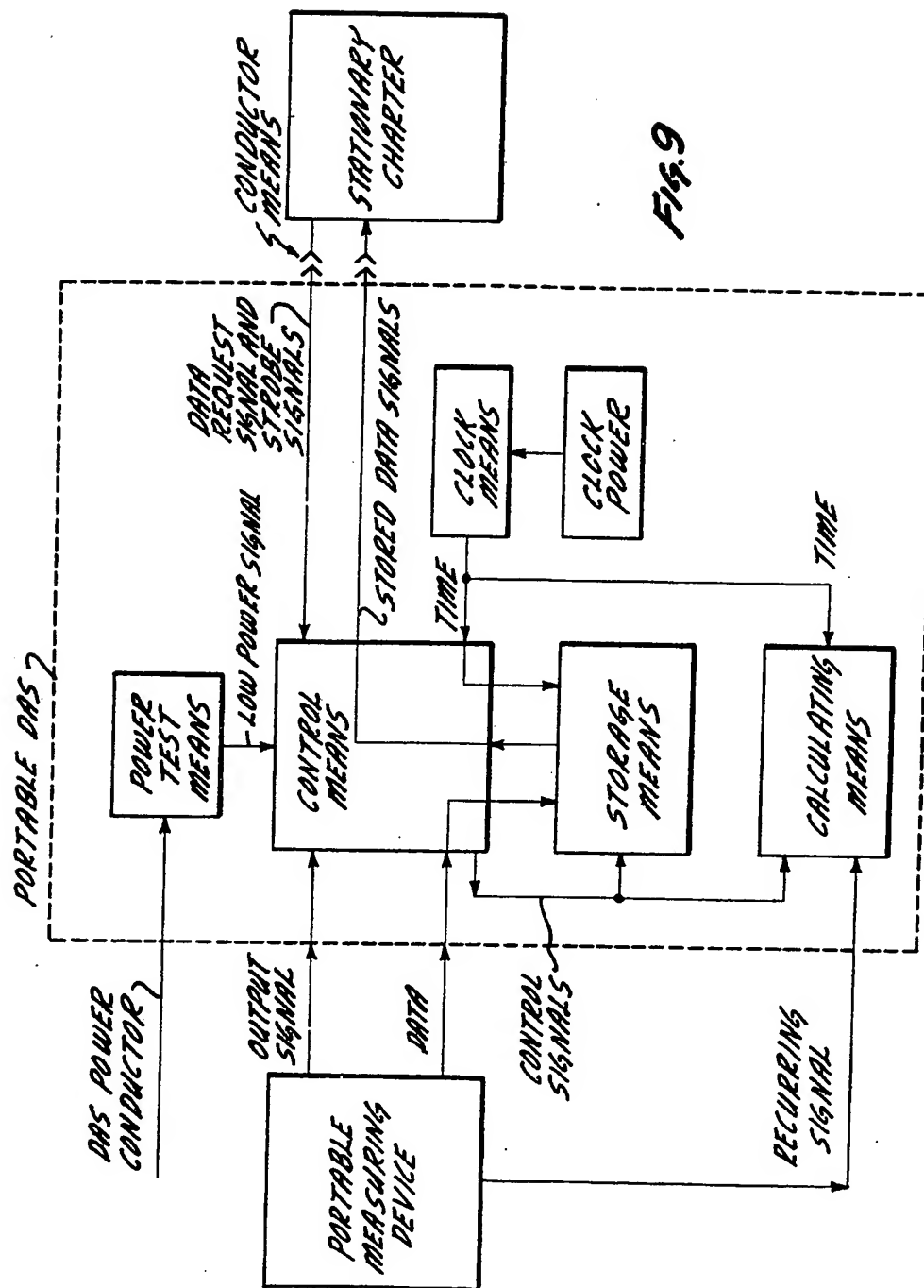


Fig. 7
FLOW CHART OF
MAIN SOFTWARE
ROUTINE







SPECIFICATION

Data acquisition and storage system

The present invention is in the field of medical electronics, and more specifically, relates to a

- 5 compact, battery-operated data acquisition and storage device to be worn by ambulatory patients to facilitate physiological assessment of the condition of cardiac or hypertensive patients. Although the present invention has no moving
- 10 parts, it performs all the functions of and replaces the portable tape recorder generally used in the art of ambulatory monitoring.

- In ambulatory monitoring as normally practiced, the patient wears a device for
- 15 measuring or sensing the physiological variables to be monitored, such as ECG waves, EEG waves, blood pressure, heart rate, etc. As practiced in the prior art, the patient also wears a miniaturized portable magnetic tape recorder which records the
- 20 successive values of the physiological signal obtained from the sensors. After the recording session, which may last twenty-four hours or more, the magnetic tape is returned to the clinic where the tape is played back on suitable
- 25 equipment so that the signals can be recovered and analyzed. The signals from the playback apparatus are typically applied to the printer-plotter or charter which produces a graphical chart record, as well as numerical data.

- 30 Various factors limit the ability of the designers of the tape recorder to reduce its weight and size, these being primarily the amount of continuous data recorded and the necessity of accurate reproduction of continuous analog information
- 35 such as ECG waveforms from the recording into diagnostic quality results. Even though the recording speed for ECG waveforms is made relatively slow in order to sufficiently compact the data, the tape requires considerable length and
- 40 space. Sufficient battery must be provided to power the tape-drive motor reliably for the entire duration of the monitoring session, and this adds considerable weight. The tape-drive motor normally includes heavier ferromagnetic elements.
- 45 Such tape recorders are highly developed and sophisticated instruments designed to do their job with a minimum of weight, but nevertheless, even if not burdened with recording of continuous waveforms over a long recording period, such
- 50 recorders are complicated and are subject to wear of moving parts. Also, the portable magnetic tape recorder tends to be expensive to produce because it must be carefully engineered to minimize power consumption and to operate
- 55 extremely quietly. A less expensive acceptable substitute would be highly desirable.

- An acceptable substitute for the magnetic tape recorder that could accomplish quality recording while having no moving parts, no noise, and high
- 60 reliability would be considered a worthwhile advance in the art.

Contemporary playback apparatus used to recover long-term recorded ECG and blood pressure data from magnetic tapes is typically very

- 65 sophisticated. To save time, the apparatus is made capable of playing back the tape at a higher speed than the speed at which it was recorded and of analyzing the data on the tape as the tape is played back. The operator can select the type of
- 70 analysis he prefers. The more sophisticated analyzers can recognize the occurrence of waveforms associated with a number of heart disorders and can display the data in ways which facilitate closer study of the more interesting
- 75 cardiac episodes. A contemporary apparatus for playback and analysis of the recorded tapes is described in U.S. Patent No. Re 29,921, reissued February 27, 1979 to Isaac R. Cherry and Donald L. Anderson for "Electrocardiographic Computer."

- 80 Clearly, if the magnetic tape could be eliminated, the need for at least the mechanical variable-speed tape playback portion of the analyzer would also be eliminated. Until the present invention, there existed no satisfactory
- 85 substitute for the magnetic tape and its associated recorder and playback equipment in long-term cardiac monitoring. The present invention changed this situation by demonstrating an advantageous substitute for the magnetic tape
- 90 system which should show the way for future development of the ambulatory monitoring art.

- Prior to summarizing the innovative aspects of the present invention, the equipment with which it will be used will be described briefly. That
- 95 equipment includes: blood pressure measuring apparatus for ambulatory patients, available under the registered trademark PRESSUROMETER® II from the assignee of the present invention, Del Mar Avionics, of Irvine, California; a magnetic tape
- 100 recorder for ambulatory patients known as the Del Mar Avionics Model 447; and an intelligent printer-plotter known as the PRESSUROMETER® CHARTER, available from the same source. Readers familiar with instruments of these types
- 105 may choose to turn directly to the section entitled "Summary of the Invention."

- The blood pressure measuring apparatus with which the data acquisition and storage system of the present invention is used is described in U.S. Patent Application Serial No. 796,893 filed May
- 110 17, 1977 by W. David Squires, Donald L. Anderson and Isaac Raymond Cherry for "Blood Pressure Monitoring System", the disclosure of which is incorporated herein by reference. The
- 115 blood pressure measuring apparatus operates on the auscultation method, employing a pressurizable cuff and requiring no intervention by the patient. ECG signals are sensed by ECG electrodes, and a microphone is used to sense the
- 120 Korotkow sounds as the pressure in the cuff is varied. The presence or absence of a Korotkow sound within a preset interval following each heart beat is used in determining when the cuff pressure successively equals the systolic and diastolic
- 125 pressures. Those pressures are determined in each cycle of operation and are recorded on a continuously-running portable tape recorder, along with the ECG signals.

In each cycle of operation of the blood pressure

monitoring system, the initial pressure to which the cuff is inflated is based on the systolic pressure measured in the immediately preceding cycle. The pressure in the inflated cuff is thereafter stepped downward in small discrete decrements triggered by successive R-waves of the ECG signal during the measurement phase of each cycle. After both the systolic and diastolic pressures have been determined, the remaining cuff pressure is vented through the same valve that was used to produce the stepwise pressure reduction. After a number of cycles of operation, the magnetic tape is removed from the portable recorder and inserted into an analyzer for high-speed playback and automated plotting of the heart rate and accompanying blood pressure readings on a common chart.

The magnetic tape recorder with which the data acquisition and storage system of the present invention is normally used is described in U.S. Patent Application Serial No. 918,698 filed June 23, 1978 by Stephen K. Shu and W. David Squires for "Apparatus for Recording and Playing Back Electrocardial Signals", the disclosure of which is incorporated herein by reference. The tape recorder encodes and records the blood pressure measurements obtained from a patient on a particular track on a two-track magnetic tape, and a channel of continuous ECG signals are also recorded on the same track as the blood pressure data, along with time-of-day-signals and event-marker signals. The ECG signal is recorded in analog form, but the other signals are recorded as pulse-coded signals, each coded in its own format. The other track of the two-track tape is dedicated to an uninterrupted recording of a continuous ECG signal.

The stationary charter with which the portable blood pressure measuring apparatus and the portable data acquisition and storage system of the present invention are normally used is described in U.S. Patent Application Serial No. 959,091 filed November 9, 1978 for "Charter With Automatic Editing" by John A. Ripley, Donald C. Woods, and James Kaine. As disclosed therein, the charter is an intelligent printer-plotter for use with a source of time-correlated digital systolic and diastolic blood pressure data and heart rate data. The source may also include coded time signals and event-marker signals. After the conclusion of the monitoring session, when it is desired to transfer the data from the portable apparatus into the charter for plotting, the portable apparatus is brought to the location of the stationary charter, and the data acquisition and storage system is then connected electrically to the charter. Power is then applied to the charter, and the DATA LOAD button on the charter is depressed. This causes the charter to generate a SERVICE REQUEST signal which the charter applies to the data acquisition and storage system. The data acquisition and storage system acknowledges the SERVICE REQUEST signal by applying to the charter a signal representing the number of valid data readings that are available

for transfer. Only then is the digital data transferred from the data acquisition and storage system to the charter in response to a predetermined number of strobe pulses generated by the charter and applied to the DAS.

The charter receives, stores, analyzes, and edits the data, producing tables of data and graphs having a particular format. The charter smoothes the data by a moving average technique and includes modes which permit the operator to edit the data manually or to command the charter to perform the editing automatically. In the automatic editing mode, the data are tested against pre-established criteria designed to determine if the values of the variables are plausible. Data not meeting the criteria are flagged so they can be passed over in subsequent calculation and printing operations if that is desired; however, the flagged data is not destroyed, but is retained in a memory to permit subsequent re-examination and to permit verification of the editing process.

The Data Acquisition and Storage System (DAS) of the present invention has no moving parts and is a computerized substitute for the magnetic tape recorder of the prior art worn by the patient during ambulatory monitoring. The DAS functions like a magnetic tape recorder in that it stores the data for later read-out, it generates and stores a time signal so that the measurement times can be determined, and it protects against loss of the stored data in the event the power fails. However, compared with a magnetic tape recorder, the DAS has a number of unique advantages. From the standpoint of patient comfort, the DAS is lighter in weight than the recorder. Maintainability of the DAS should prove to be good because of the lack of moving parts and freedom from magnetic tape playback equipment.

The DAS is an active device having control and computational capabilities. These capabilities are exploited in a preferred embodiment of the present invention to calculate heart rate, and in other embodiments various derived variables can be calculated from the data received by the DAS, including data processing operations such as smoothing, differentiating, and integrating the data. The DAS in a preferred embodiment also performs certain control functions, such as testing the condition of its power source so that if the applied power is not adequate, the DAS enters a power-conserving mode in which the stored data is preserved. Further, the DAS includes a clock for determining the times at which the measurements are made. Thus, it is apparent that these control and computational capabilities distinguish the DAS from a simple solid state memory.

The novel features which are believed to be characteristic of the invention, both as to organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which the preferred

embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the invention.

Figure 1 is a block diagram of a prior art system used for obtaining and producing a chart of the blood pressure and heart rate of a patient during an ambulatory monitoring session;

Figure 2 is a block diagram of a system for obtaining and charting the blood pressure and heart rate of a patient in which the present invention is employed;

Figure 3 is a perspective view showing the relationship of the present invention to the other apparatus with which it is used;

Figure 4 is a block diagram showing a preferred embodiment of the data acquisition and storage system of the present invention;

Figure 5 is a graph showing the waveforms of certain signals used in a preferred embodiment of the present invention versus time;

Figure 6 is a diagram showing the format of the output data signal of the DAS in a preferred embodiment;

Figure 7 is a flow chart of the main program used in a preferred embodiment of the present invention;

Figure 8 is a flow chart of an auxiliary routine used in a preferred embodiment of the present invention; and,

Figure 9 is a block diagram showing the present invention in a greater degree of generality.

Turning now to the drawings, in which like parts are denoted by the same reference numeral throughout, there is shown in Figure 1 a prior art system for measuring, recording, playing back, and charting the blood pressure and ECG waveform of a patient. ECG electrodes 12, an inflatable cuff 14, and a microphone 16 are affixed to the patient's body at appropriate locations and with the microphone 16 positioned between the cuff 14 and the patient's arm. It is also necessary for the patient to wear a tape recorder 18 as well as a portable blood pressure measuring system 20. As shown in Figure 1, the ECG electrodes 12 are connected directly to the tape recorder since one channel of the magnetic tape is dedicated to a particular channel of ECG signals. However, ECG signals are applied, as indicated, by the tape recorder to the blood pressure measuring system 20 for use in triggering a series of small pressure decrements in the cuff pressure. The blood pressure measuring system 20 determines in succession the systolic blood pressure and the diastolic blood pressure. The blood pressure data is encoded and applied to the portable magnetic tape recorder 18 which records the data on the magnetic tape 22. All of the components mentioned thus far are portable.

At the conclusion of the ambulatory monitoring session, the magnetic tape 22 is taken to the location of the stationary playback and charting equipment. The tape 22 is then inserted into the

playback apparatus 24 which may also include circuitry for analyzing the ECG signal and determining the heart rate, the number of ectopic beats, and other desirable information. Electrical signals generated by the playback apparatus 24 represent the various quantities of interest, and these signals are applied to a plotter 26 which produces a chart 28 of the information. The playback apparatus 24 and the plotter 26 are stationary and are usually located in a clinic where they are operated by trained personnel.

Figure 2 is a block diagram of the system with which the Data Acquisition and Storage system (DAS) 10 of the present invention is used. In comparison to Figure 1, it can be seen that the system of Figure 2 also employs ECG electrodes 12, a cuff 14, and a microphone 16 all affixed to the patient as well as a portable blood pressure measuring system. The striking difference is that in the system of Figure 2 the tape recorder 18, the magnetic tape 22, and the playback apparatus 24 have been replaced by the DAS 10 of the present invention. The charter 30 used in the system of Figure 2 is a different device from the plotter 26 used with the system of Figure 1, and likewise, the chart 32 produced by the charter 30 is significantly different.

The blood pressure measuring apparatus 20 of Figure 2 is very similar to that used in the system of Figure 1. Several minor modifications have been made to the blood pressure measuring apparatus to permit the ECG leads 34 to be connected directly to it and to bring a clock signal on one of the lines 36 from the blood pressure measuring apparatus 20 to the DAS 10. As noted above, the blood pressure measuring apparatus 20 and the charter 30 of Figure 2 are the subject matter of co-pending applications, to which reference should be made for a fuller description. The present invention is the DAS 10 of Figure 2.

Figure 3 is a perspective view showing the blood pressure measuring system 20, the charter 30, and the DAS 10. Physically, the DAS circuitry is mounted on a circuit board 38 which is attached to the blood pressure measuring apparatus 20 so as to become a part of it. The connector 40 provides the electrical interconnection between the blood pressure measuring apparatus 20 and the DAS 10, and the cable 42 serves as an electrical interconnection with the charter 30. The cable 42 is interrupted by the connector 44 to permit the portable components to be separated from the stationary charter 30.

Figure 4 is a block diagram of a preferred embodiment of the DAS of the present invention. The current to operate the nominal +5 volt CMOS logic in its normal mode is derived from the nominal +7.5 VDC battery in the blood pressure measuring apparatus 20 and the interface connector 40 includes paths for the +7.5 DC supply as well as a ground return path. A voltage regulator 46 maintains the voltage at junction point 48 at +5 VDC. Operating current can also be supplied to junction point 48 from two other sources when the +7.5 VDC battery of the blood

pressure measuring apparatus 20 is depleted or removed. Assuming that the DAS is not connected to the charter 30, the alternative battery power source 50 will automatically supply current to the junction 48 when the voltage at the junction drops to a value approximately 0.4 volts less positive than the auxiliary battery voltage, due to the forward voltage drop of the diode 52. The auxiliary battery 50 is trickle-charged through the resistor 54 whenever the voltage at the junction 48 exceeds the auxiliary battery voltage. The CMOS logic in the DAS will operate on voltages measured at the junction 48 as low as +3 VDC. Current can also be supplied to the junction 48 from the +5 VDC power supply in the charter 30 through the connector 44 via the line 56, the latter being connected to the junction 48 through the diode 58.

An eight-bit CMOS microprocessor 60 in conjunction with a firmware program contained in the Programmable Read Only Memory (PROM) 62 controls the data acquisition, storage, and communication functions of the DAS. In the preferred embodiment, the microprocessor 60 is a commercially available type known as an RCA CDP 1802. The microprocessor 60 addresses the PROM 62 and the Random Access Memory (RAM) 64 through an eight-line multiplexed address bus 66. The microprocessor control signal, "TPA", on the line 68 automatically latches the most significant eight bits of the sixteen-bit address into the address latch 70 at the proper time during the microprocessor instruction cycle. The three least significant bit lines from the address latch 70 are brought to the address decode logic 72 which selects 1 of 8 blocks of either PROM or RAM memory via the chip select lines 74. Each block of memory is organized into 256×8 bits. The time at which a block of memory is selected is different from the standard RCA system because of the utilization of latched-address PROM 62 and RAM 64 memories specific to the preferred embodiment. The high-to-low transition of the "MRD" line 76 occurs when the memory address is not yet valid. In the DAS system, the high-to-low transition of the "MRD" output signal is delayed by one microprocessor clock interval by the delay logic circuit 78. The output of the delay logic circuit 78 is connected to the address decode logic 72 and serves to activate one of the chip select lines 74.

The PROM 62 is a CMOS fusible-link-programmed memory organized in 2 blocks or pages of 256×8 bits, making a total of 512×8 bits for the program memory. The RAM 64 also is a CMOS memory organized in 6 blocks or pages of 256×8 bits, making a total of $1,536 \times 8$ bits of volatile storage memory. The PROM 62 and the RAM 64 send to and receive information from the microprocessor 60 via the 8-bit bi-directional data bus 66.

The microprocessor accepts four direct input lines labelled "EF1", "EF2", "EF3", and "EF4". These lines can be interrogated by software instructions to test directly whether a logic high

level or a logic low level is present. In addition to these direct input lines, an 8-bit input port 80 is provided. Two input lines 82, 84 are connected to the input port 80. The line 82 carries a "LOW POWER" signal from the Low Voltage Detect Circuit 86 to the input port 80. The "strobe data in" line 84 is a handshaking line by which the charter 30 signals the DAS by bringing the "strobe data in" line from a logic high level to a logic low level, thereby latching the input data bit on the line 90 into the input port 80. The input port responds to this external request by bringing the "data present" line 88, which is connected to the EF4 input of the microprocessor 60, from a logic high to a logic low level. The program software then periodically polls the EF4 line to ascertain whether the charter 30 is requesting data from the DAS. The input port is selected by the "MRD" signal on the line 76 from the microprocessor 60 and the "input port select" line 90 from the decoder 92. The decoder 92 receives inputs from three microprocessor lines, "N0", "N1", and "N2", which are activated when certain software input or output instructions are executed. One of seven input or output function lines are selected by the 3-line-to-8-line decoder 92. Any one of the output lines from the 3-to-8 decoder 92, when selected, will output a logic high level pulse for the duration of seven microprocessor clock intervals (seven microseconds).

The eight-bit output port 93 is selected by the "output port select" line 94 and the microprocessor-generated control signal "TPB" on the line 96. The output port, in response to a software output instruction, latches eight bits of data from the data bus 98 and presents four of these bits to the charter 30 through the connector 44 on the four lines 100. In addition, the output port generates a logic high pulse on the "service request" line 102 of duration eight microprocessor clock cycles (eight microseconds). The "service request" output signifies to the charter 30 that four bits of data are valid on the data lines 100.

The Power-up Reset Circuit 105 generates a logic low pulse only when a new battery has been installed in the blood pressure measuring apparatus 20 and the +7.5 VDC voltage input on the power conductor 104 changes from zero volts to +7.5 VDC. The microprocessor 60 receives this pulse at its "CLEAR" input via the line 106 and executes an internal reset sequence including starting to execute the program stored in the PROM 62 at address location zero. If the +7.5 VDC battery voltage should decrease to zero, the DAS will continue to operate on the auxiliary battery 50. The Low Voltage Detect Circuit 86 senses when the +7.5 VDC voltage input drops below approximately +5 VDC. When this condition occurs, the line 82 changes from a logic high level to a logic low level which is the "LOW POWER" signal applied on the line 82 to the eight-bit input port 80. The software program polls this input line periodically, and if it ever is found to be at a logic low level, the program

branches to a power-conservation subroutine. This subroutine via an output instruction sends a seven microsecond pulse on the "power down" line 108 which sets a flip-flop in the Power Conservation Logic Circuit 110. The logic low level inverted output of the flip-flop is connected to the "WAIT" input of the microprocessor 60 via the line 112. A logic low level on the "WAIT" line puts the microprocessor 60 into a "pause mode" which halts all internal microprocessor operations except the internal clock operation. This has the result of reducing the DAS current consumption to less than 300 microamps. A "DAS ACTIVATE" signal from the charter 30 on the line 114 is used to reset the flip-flop in the Power Conservation Logic circuit 110. When the "WAIT" line is brought to the logic high level, the microprocessor 60 resumes program execution at exactly the location in the microprocess cycle that it left off when put into the "pause mode".

A "DAS DETECT" signal on the line 116 is sent to the blood pressure measuring apparatus 20 where it is used to control an analog gate which disallows the blood pressure measuring apparatus 20 from sending output signals to the recorder jack 118 of Figure 3, and allows continuous ECG information to be input through that jack from the patient's electrodes 12 of Figure 3. The ECG signal is conditioned in the blood pressure measuring apparatus 20 as described in the aforementioned pending patent application, and the ECG signal is presented to the DAS on the "ECG R-wave" line 120. Figure 5 illustrates the "ECG R-wave" waveform 122 which consists of logic high level pulses of approximately 20 milliseconds duration, with the leading edge of each pulse corresponding to the occurrence of the R-wave. These pulses are applied to the ECG R-wave conditioning circuit 124.

The leading edge of the "ECG R-wave" waveform 122 sets a flip-flop in the ECG R-wave conditioning circuit 124, and the output of the flip-flop is connected via the line 126 to the microprocessor 60 flag input "EF3". The software interrogates "EF3" to detect the occurrence of an R-wave and resets the flip-flop of the ECG R-wave conditioning circuit 124 via an output instruction which generates a signal applied to the decoder 92 which generates a pulse on the "R-wave reset line" 128.

The "32 Hz clock" signal 130 of Figure 5 is a crystal-controlled timing signal generated in the blood pressure measuring apparatus 20 and brought into the DAS on the line 132 of Figure 4. The rising edge of this signal sets a flip-flop in the Interrupt Logic Circuit 134, which generates a logic low level and applies it to the "Interrupt" input of the microprocessor 60 via the line 136. When the microprocessor 60 acknowledges the interrupt, it generates an "INTERRUPT RESET" signal on the line 138, that resets the flip-flop of the Interrupt Logic Circuit 134 in readiness for the next interrupt.

Blood pressure data is presented to the microprocessor 60 at its "EF2" input via the

"serial data in" line 140. Referring to Figure 5, the blood pressure information is transmitted as a 16-bit serial binary bit stream 144 on the "serial data in" line 140. The systolic blood pressure is transmitted first with the most significant bit first, followed by the diastolic blood pressure with its most significant bit first.

Transfer of the blood pressure data from the blood pressure measuring apparatus 20 into the DAS is initiated by an "ENTER DATA" signal 146 of Figure 5, on the "enter data" line 142. The "ENTER DATA" signal 146 is identical to the DATA VALID signal referred to in the co-pending application on the blood pressure measuring apparatus. When the "ENTER DATA" line 142 goes to a logic high level, the first blood pressure bit is valid on the rising edge of the "32 Hz clock" signal 130 and is presented on the "serial data in" line 140. Succeeding data bits are valid on every other rising edge of the "32 Hz clock" line until all sixteen bits have been transmitted and the "ENTER DATA" signal 146 returns to a logic low level.

Figure 7 is a flow chart of the main program for the microprocessor 60 of the DAS. The program is stored in the PROM 62, which, it will be recalled, is a CMOS fusible-link-programmed memory organized in two blocks or pages of 256×8 bits, for a total of 512×8 bits. The instructions are transmitted from the PROM 62 to the microprocessor 60 over the eight-bit bi-directional bus 66. The operation of the microprocessor is controlled by the program of instructions in the PROM 62, and those instructions are summarized in the flow charts of Figures 7 and 8 in a preferred embodiment. It is well known in the art that there is no *unique set of instructions* for implementing the flow charts of Figures 7 and 8, and alternative sets of instructions are deemed to be obvious to those skilled in the art. However, the flow charts of Figures 7 and 8 *characterize the preferred embodiment* of the invention, although alternative embodiments will be discussed below.

As shown in Figure 7, the operation blocks 148, 150, 152 together constitute an initialization subroutine which is initiated by the Power Up Reset Circuit 105, which, it will be recalled, generates a logic low level pulse only when a new battery has been installed in the blood pressure monitoring apparatus 20 and the +7.5 VDC voltage input on the power conductor 104 changes from zero volts to +7.5 VDC. The microprocessor 60 receives this pulse at its "CLEAR" input via the line 106 and executes an internal reset sequence including beginning to execute the program stored in the PROM memory 62 at the address location zero.

Upon completion of the initialization operations 148—152, the main routine begins with the decision block 154 which asks whether a heart rate flag is set. As seen in Figure 8, the heart rate flag is set only after the blood pressure readings have been entered into the RAM 64 from the blood pressure measuring apparatus 20, at which point it becomes necessary to calculate the heart

rate based on this most recently received data. If the heart rate flag is set, then it indicates that a new set of blood pressure readings have been received, along with a time-of-day signal, and the program branches to the operation blocks 156, 158 and 160.

As can be seen from these three operation blocks, in a preferred embodiment, the heart rate is calculated by measuring the time interval between nine consecutive heart beats, which is determined by nine successive pulses on the line 126 of Figure 4. The software contains provision for taking the reciprocal of the time interval in seconds and multiplying it by 540 to obtain the heart rate in beats per minute. It is noted that the operation block 160 resets the heart rate flag, so that the heart rate computation implemented by the blocks 156—160 is not repeated again until another set of blood pressure readings becomes available. Thus, after the operation block 160, the program resumes by returning to the input to the decision block 154. Normally, the blood pressure readings occur only once every 7.5 minutes, and therefore, on the second pass through the decision block 154 the heart rate flag is found not to be set, and the program therefore proceeds to the decision block 162.

In a preferred embodiment of the invention, the decision block 162 asks the question whether a low battery condition exists. As discussed above, this is determined by the Low Voltage Detect Circuit 86 of Figure 4 which generates a "LOW POWER" signal on the line 82 when a low battery voltage is detected. If a low battery condition exists, the program branches to the operation blocks 162, 166, 168. These blocks provide for an orderly termination of further microprocessor activities and provide for the application of power to only the CMOS RAM 64 of Figure 4 to preserve the accumulated data and to the time-keeping circuits to provide for continued running of the time-of-day clock. Once the microprocessor has been put in the "pause mode" by the operation block 168, the program returns to the junction 153 at the beginning of the main routine. If a low battery condition does not exist, the program progresses from the decision block 162 to the decision block 170. In another embodiment of the present invention, the blocks 162, 164, 166, and 168 are eliminated from the flow chart and the orderly termination of further microprocessor activities is initiated and implemented by hardware circuitry.

The decision block 180 asks whether the charter 30 has requested service. As described above, this is determined by the presence of a data request signal on the line 90 from the charter 30. More often than not, the charter is not requesting data, and the program returns to the junction 153 at the beginning of the main routine. In the event the charter 30 is requesting service, the program progresses to the blocks 172—178 of Figure 7. The blocks 172, 172 implement a test to determine whether the transfer of a series of blood pressure readings from the DAS to the

charter 30 is already in progress. If the transfer is already in progress, the line 90 of Figure 4 is at a logic low level and the transfer continues via the block 178. If the transfer has not yet begun, the operation block 176 provides that the charter 30 will be given a number representing the total number of blood pressure readings available for transfer, so the charter 30 can initiate only that number of strobe pulses. Figure 6 shows the format of the output data transmitted from the DAS to the charter 30.

Figure 8 is a flow chart of the interrupt subroutine of the program in a preferred embodiment. The initial block 180 increments a clock which is used for keeping track of the time of day. The interrupt subroutine of Figure 8 is repeated at regular intervals, and thereby serves to keep time. The more frequent flow of the program through the flow chart is from block 180 to block 182 to block 188. However, if blood pressure data is available from the blood pressure measuring apparatus 20 as made known to the microprocessor 60 by the presence of the "ENTER DATA" signal on the line 142, the program branches at the decision block 182 and proceeds to read in, first the eight bits representing the systolic blood pressure, and then another eight bits representing the diastolic reading. When all sixteen bits of the blood pressure readings have been entered, the time of day is stored in the RAM 64 in association with the blood pressure data, and thereafter the heart rate flag is set by the operation block 186. The program returns to the main program of Figure 7 by virtue of the operation block 188.

Thus, it is seen that the block 186 sets the heart rate flag which, after the program has returned to the main routine of Figure 7, results in the program's branching at the decision block 154 to the heart rate calculation blocks 156, 158. In an alternative embodiment, additional calculation blocks are inserted between the block 158 and the block 160 to provide for the calculation of a moving average, and the calculation of a derivative, or integral of a stored variable. These additional calculations are made possible by the fact that the time of day associated with the arrival of the blood pressure signals from the blood pressure measuring apparatus 20 is stored in association with those signals by the block 184 of Figure 8. In the alternative embodiment, after the other variables derived from the basic data have been calculated, the program progresses to the block 160 of Figure 7 which resets the heart rate flag. The calculated values of the derived variables are stored in the RAM 64 for subsequent application to the charter 30. Alternatively, although heart rate is of considerable interest in the preferred embodiment which is oriented to heart monitoring applications, it is altogether conceivable that the instructions which calculate the heart rate and the preferred embodiment could be replaced by a different set of instructions which operate the microprocessor 60 to calculate a different mathematical function of the received

data, including but not limited to, moving averages, derivatives, and integrals.

Figure 9 is a functional block diagram stating the present invention in its broadest expression.

5 Figure 9 is presented to facilitate the obtaining of an overview of the system and the reading of the claims.

Thus, there has been described a data acquisition and storage system for use with a blood pressure apparatus. Both the DAS and the blood pressure measuring apparatus are portable and are normally worn by the patient. After the ambulatory monitoring session is finished, the DAS is brought to the clinic and connected electrically to a charter, which provides a graphical record of the recorded variables in the form of tables of data and charts. As pointed out above in connection with Figures 1 and 2, the DAS of the present invention is a replacement for the magnetic tape previously used to store the data during the ambulatory monitoring session. Unlike the magnetic tape recorder used in the prior art, the DAS of the present invention has no moving parts and is lighter, cheaper, and more reliable.

25 The DAS of the present invention includes a clock by means of which the time of arrival of each successive word of incoming data is determined, and the times of arrival are stored in association with the data so that the data may be recovered in the proper chronological sequence and the time interval between successive events preserved. In a preferred embodiment, the time-of-day clock continues to run even if the blood pressure measuring apparatus is turned off or disconnected so that the correct time of day will be available when the blood pressure measuring apparatus is subsequently turned on again or plugged in again.

The DAS of the present invention further includes provision for calculating the heart rate of the patient each time a blood pressure reading is obtained, and this data, along with the time of day, is stored with the blood pressure readings.

In a preferred embodiment of the present invention, the DAS includes means to test the voltage of the power source to determine whether it is adequate. If the voltage is found to be low, indicating that the battery is becoming weak, the DAS assumes a dormant mode of operation which prevents erroneous readings from being passed on to the charter, but which preserves the valid readings already stored in the memory of the DAS.

The particular utility of the present invention in connection with ambulatory monitoring of blood pressure and heart rate does not detract from its utility in replacing a portable magnetic tape recorder for the ambulatory monitoring of other physiological variables concerning a patient and his environment. Such variables include without limitation, body and body environment temperatures, body environmental exposures, such as altitude, wind velocity and gamma, X-ray, or infra-red radiation, respiration volume and rate, the concentration of various chemicals in the blood, ECG, EEG, etc. Obviously, the DAS will

accept and operate on signals representing any of the aforementioned variables provided the signal has the correct format. Again, in this context, the DAS of the present invention is a very satisfactory substitute for a magnetic tape recorder.

CLAIMS

1. A Data Acquisition and Storage system (DAS) worn by a patient, for use with a portable measuring device also worn by the patient to permit ambulatory monitoring of a physiological variable measured by the portable measuring device, and for storing successive values of the physiological variable, said DAS being connectable to a stationary charter for producing a graphical record of the stored values, the measuring device generating and applying to said DAS an OUTPUT signal when a measurement is obtained, an electrical data signal representative of the measured value, and a recurring signal, the charter when connected to said DAS generating and applying to said DAS a DATA REQUEST signal for initiating a transfer by the DAS of the stored values to the charter, said DAS comprising in combination: storage means worn by the patient and having no moving parts, for storing electrical signals; control means connected to the portable measuring device worn by the patient, and responsive to the OUTPUT signal generated by the portable measuring device when a measurement is obtained to enter the electrical data signal representative of the then measured value of the physiological variable into said storage means; conductor means for selectively connecting said control means to the stationary charter, said control means responsive, when thus connected, to the DATA REQUEST signal applied to said DAS by the charter to initiate application of the signals stored in said storage means to the charter; clock means for generating a time signal, said control means entering the time signal into said storage means in response to the OUTPUT signal so that each data signal is associated with a time signal indicating when the measurement represented by the data signal was obtained, said control means applying the time signals to the charter along with the signals stored in said storage means.

2. The DAS of Claim 1 wherein said portable measuring device produces a recurring signal, and further comprising calculating means connected to the portable measuring device to receive the recurring signal, and connected to said clock means to receive the time signal, and operative to determine the rate of recurrence of the recurring signal.

3. The DAS of Claim 2 wherein said calculating means calculates the rate of recurrence of the recurring signal by determining the time required for the occurrence of a preset number of recurrences.

4. The DAS of Claim 1 further comprising calculating means connected to said storage means for producing an electrical signal representing calculated values of a derived variable from the stored electrical signals

representing the measured values, and for entering the electrical signals thus produced in said storage means.

5 The DAS of Claim 4 wherein said control means are connected to said calculating means and initiate operation of said calculating means in response to the OUTPUT signal.

6. The DAS of Claim 4 wherein said calculating means employ the time signals that have been entered into said storage means to calculate the rate of change of a physiological variable.

7. The DAS of Claim 1 further comprising clock power means for providing said clock means with an uninterrupted supply of power independently of whether the portable measuring device is in operation, whereby the clock signals are related to the time of day at which measurements are obtained even when the portable measuring device is operated intermittently.

8. The DAS of Claim 1 further comprising: a DAS power conductor for supplying electrical power to the DAS; and power test means connected to said DAS power conductor for generating and applying to said control means a LOW POWER signal when an electrical characteristic of the electrical power supplied is less than a specified level.

9. The DAS of Claim 8 wherein in response to said LOW POWER signal, said control means begins to operate in a power conserving mode but continues to permit power to be applied to said storage means to preserve the data stored therein.

10. A Data Acquisition and Storage system (DAS) worn by a patient, for use with a portable measuring device also worn by the patient to permit ambulatory monitoring of a physiological variable measured by the portable measuring device, for storing successive values of the physiological variable, and for calculating values of a derived variable from the successive values of the physiological variable, said DAS being connectable to a stationary charter for producing a graphical record of the stored values and the values of the derived variable, the measuring device generating and applying to said DAS an OUTPUT signal when a measurement is obtained, an electrical data signal representative of the measured value, and a recurring signal, the charter when connected to said DAS generating and applying said DAS a DATA REQUEST signal for initiating a transfer by the DAS of the stored values and the values of the derived variable to the charter, said DAS comprising in combination: storage means worn by the patient and having no moving parts, for storing electrical signals; control means connected to the portable measuring device worn by the patient, and responsive to the OUTPUT signal generated by the portable measuring device when a measurement is obtained to enter the electrical data signal representative of the then measured value of the physiological variable into said storage means; conductor means for selectively connecting said control means to the stationary charter, said control means responsive, when thus connected,

to the DATA REQUEST signal applied to said DAS by the charter to initiate application of the signals stored in said storage means to the charter; clock means for generating a time signal, said control means entering the time signal into said storage means in response to the OUTPUT signal so that each data signal is associated with a time signal indicating when the measurement represented by the data signal was obtained, said control means applying the time signals to the charter along with the signals stored in said storage means; and, calculating means connected to the portable measuring device to receive the recurring signal, and connected to said clock means to receive the time signal, and operative to determine the rate of recurrence of the recurring signal.

11. The DAS of Claim 10 wherein said calculating means calculates the rate of recurrence of the recurring signal by determining the time required for the occurrence of a preset number of recurrences.

12. The DAS of Claim 10 wherein said calculating means further comprise means connected to said storage means for producing an electrical signal representing calculated values of a derived variable from the stored electrical signals representing the measured values, and for entering the electrical signals thus produced in said storage means.

13. The DAS of Claim 12 wherein said control means are connected to said calculating means and initiate operation of said calculating means in response to the OUTPUT signal.

14. The DAS of Claim 12 wherein said calculating means employs the time signals that have been entered into said storage means to calculate the rate of change of a physiological variable.

15. The DAS of Claim 10 further comprising clock power means for providing said clock means with an uninterrupted supply of power independently of whether the portable measuring device is in operation, whereby the clock signals are related to the time of day at which measurements are obtained even when the portable measuring device is operated intermittently.

16. The DAS of Claim 10 further comprising: a DAS power conductor for supplying electrical power to the DAS; and power test means connected to said DAS power conductor for generating and applying to said control means a LOW POWER signal when an electrical characteristic of the electrical power supplied is less than a specified level.

17. The DAS of Claim 16 wherein in response to said LOW POWER signal, said control means begins to operate in a power conserving mode but continues to permit power to be applied to said storage means to preserve data stored therein.

18. A Data Acquisition and Storage system (DAS) worn by a patient, for use with a portable measuring device also worn by the patient to permit ambulatory monitoring of a physiological variable measured by the portable measuring

device, for storing successive values of the physiological variable, and for calculating values of a derived variable from the successive values of the physiological variable, said DAS being

5 connectable to a stationary charter for producing a graphical record of the stored values and the values of the derived variable, the measuring device generating and applying to said DAS an OUTPUT signal when a measurement is obtained,

10 an electrical data signal representative of the measured value, and a recurring signal, the charter when connected to said DAS generating and applying to said DAS a DATA REQUEST signal for initiating a transfer by the DAS of the stored

15 values and the values of the derived variable to the charter, said DAS comprising in combination: storage means worn by the patient and having no moving parts, for storing electrical signals; control means connected to the portable measuring

20 device worn by the patient, and responsive to the OUTPUT signal generated by the portable measuring device when a measurement is obtained to enter the electrical data signal representative of the then measured value of the physiological variable into said storage means;

25 conductor means for selectively connecting said control means to the stationary charter, said control means responsive, when thus connected, to the DATA REQUEST signal applied to said DAS by the charter to initiate application of the signals stored in said storage means to the charter; clock

30 means for generating a time signal, said control means entering the time signal into said storage means in response to the OUTPUT signal so that each data signal is associated with a time signal

35 indicating when the measurement represented by the data signal was obtained, said control means applying the time signals to the charter along with the signals stored in said storage means;

40 calculating means connected to the portable measuring device to receive the recurring signal, and connected to said clock means to receive the time signal, and operative to determine the rate of recurrence of the recurring signal; a DAS power

45 conductor for supplying electrical power to the DAS; and, power test means connected to said DAS power conductor for generating and applying to said control means a LOW POWER signal when an electrical characteristic of the electrical power

50 supplied is less than a specified level.

19. A Data Acquisition and Storage system (DAS) worn by a patient, for use with a portable measuring device also worn by the patient to permit ambulatory monitoring of a physiological

55 variable measured by the portable measuring device, for storing successive values of the physiological variable, and for calculating values of a derived variable from the successive values of the physiological variable, said DAS being

60 connectable to a stationary charter for producing a graphical record of the stored values and the values of the derived variable, the measuring device generating and applying to said DAS an OUTPUT signal when a measurement is obtained,

65 an electrical data signal representative of the

measured value, and a recurring signal, the charter when connected to said DAS generating and applying to said DAS a DATA REQUEST signal for initiating a transfer by the DAS of the stored

70 values and the values of the derived variable to the charter, said DAS comprising in combination: storage means worn by the patient and having no moving parts, for storing electrical signals; control means connected to the portable measuring

75 device worn by the patient, and responsive to the OUTPUT signal generated by the portable measuring device when a measurement is obtained to enter the electrical data signal representative of the then measured value of the physiological variable into said storage means;

80 conductor means for selectively connecting said control means to the stationary charter, said control means responsive, when thus connected, to the DATA REQUEST signal applied to said DAS by the charter to initiate application of the signals stored in said storage means to the charter; clock

85 means for generating a time signal, said control means entering the time signal into said storage means in response to the OUTPUT signal so that each data signal is associated with a time signal

90 indicating when the measurement represented by the data signal was obtained, said control means applying the time signals to the charter along with the signals stored in said storage means; and,

95 calculating means connected to the portable measuring device to receive the recurring signal, and connected to said clock means to receive the time signal, and operative to determine the rate of recurrence of the recurring signal, said calculating

100 means further connected to said storage means for producing an electrical signal representing calculated values of a derived variable from the stored electrical signals representing the measured values, and for entering the electrical

105 signals thus produced in said storage means.

20. A Data Acquisition and Storage system (DAS) worn by a patient, for use with a portable measuring device also worn by the patient to permit ambulatory monitoring of a physiological

110 variable measured by the portable measuring device, for storing successive values of the physiological variable, and for calculating values of a derived variable from the successive values of the physiological variable, said DAS being

115 connectable to a stationary charter for producing a graphical record of the stored values and the values of the derived variable, the measuring device generating and applying to said DAS an OUTPUT signal when a measurement is obtained,

120 an electrical data signal representative of the measured value, and a recurring signal, the charter when connected to said DAS generating and applying to said DAS a DATA REQUEST signal for initiating a transfer by the DAS of the stored

125 values and the values of the derived variable to the charter, said DAS comprising in combination: storage means worn by the patient and having no moving parts, for storing electrical signals; control means connected to the portable measuring

130 device worn by the patient, and responsive to the

- OUTPUT signal generated by the portable measuring device when a measurement is obtained to enter the electrical data signal representative of the then measured value of the physiological variable into said storage means;
- 5 conductor means for selectively connecting said control means to the stationary charter, said control means responsive, when thus connected, to the DATA REQUEST signal applied to said DAS
- 10 by the charter to initiate application of the signals stored in said storage means to the charter; clock means for generating a time signal, said control means entering the time signal into said storage means in response to the OUTPUT signal so that
- 15 each data signal is associated with a time signal indicating when the measurement represented by the data signal was obtained, said control means applying the time signals to the charter along with the signals stored in said storage means;
- 20 calculating means connected to the portable measuring device to receive the recurring signal, and connected to said clock means to receive the time signal, and operative to determine the rate of recurrence of the recurring signal; and, clock
- 25 power means for providing said clock means with an uninterrupted supply of power independently of whether the portable measuring device is in operation, whereby the clock signals are related to the time of day at which measurements are
- 30 obtained even when the portable measuring device is operated intermittently.